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Thirty-first day of March 2004

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IMPROVEMENTS IN THE DESIGN AND MANUFACTURE OF ELECTROSTATIC LOUDSPEAKERS

Field of the Invention

This invention relates to improvements in the design and manufacture of electrostatic loudspeakers.

Background to the Invention

Electrostatic loudspeakers are capable of excellent high fidelity sound reproduction, and are generally regarded as being superior in performance to conventional cone type loudspeakers. However, they have some disadvantages, which include cost of manufacture, front to back sound cancellation effects, low sensitivity, propensity to internal high voltage flashover, and inferior sound dispersion.

Summary of the Invention

The invention comprises improvements in the design and methods of manufacture of electrostatic loudspeakers which reduce or overcome known disadvantages.

There are four aspects to these improvements:

1. A method of manufacture of the grids (or stators) of an electrostatic loudspeaker, utilising flat ribbon cable.

2. A method of compensating for a reduction in output sound pressure level of an electrostatic loudspeaker, caused by front to back cancellation effects.

3. A method of limiting the peak audio frequency voltages applied to the grids of an electrostatic loudspeaker.

4. Methods of improving the sound dispersion of an electrostatic loudspeaker.

Description of Preferred Embodiments

1. Method of Manufacture of Grids (Or Stators) Using Flat Ribbon Cable

Review of Prior Art

The sound producing element of an electrostatic loudspeaker typically consists of an electrically charged diaphragm suspended in an air gap between two electrically conducting grids (or stators). The diaphragm typically consists of an ultra thin sheet of mylar, coated with a low-conductivity substance capable of holding an electric charge. Grids or stators known in the art typically comprise perforated metal sheets, wire mesh sheets, parallel wires, or perforated printed circuit boards. A typical schematic circuit diagram of an electrostatic loudspeaker is shown in Figure 1.

Diaphragm 1 is suspended between Grids (or Stators) 2. The secondary winding of Transformer 3 is connected to Grids 2. D.C. Polarising Voltage 4 is connected between Diaphragm 1 and the centre-tap of Transformer 3 secondary winding. Audio Input signal 5 is applied to Transformer 3 primary winding.

Preferred Embodiment

Figure 2 shows a typical arrangement of an electrostatic speaker grid constructed using flat ribbon cable. A number of lengths of ribbon cable are lightly tensioned between the ends of a Supporting Frame 1. The ribbon cables are positioned adjacent to each other with a small gap between adjacent cables. Figure 2, Detail D shows a method of attaching Ribbon Cable 2 to Supporting Frame 3 and a method of making electrical connection to the ribbon cable conductors via Connectors 4. The number of conductors per cable is not critical, and may be varied to suit the overall width required. The ribbon cables are clamped between a Lower Clamp 5 and an Upper Clamp 6, which are attached to Supporting Frame 3. Printed Circuit Board 7 provides means of connecting the ribbon cable conductors together to form a grid, and connecting the grid so formed to the audio transformer.

In one preferred embodiment, all the individual conductors in the ribbon cables are bridged together electrically. In a second preferred embodiment, groups of conductors are bridged together and connected to other similarly bridged groups of conductors by external means, such as delay networks.

The opposite ends of the cables are clamped to tensioning pieces which are attached to the supporting framework by tensioning means, such as tensioning screws. Figure 2, Detail E shows a means of clamping and tensioning the ribbon cables. Ribbon Cable 9 is clamped between Lower Clamp 10 and Upper Clamp 11. Tension is applied to the ribbon cable via tensioning screws or other means, and then Clamps 10 and 11 are locked to Supporting Framework 8 by tightening nuts on Studs 12, which pass through Slotted Holes 13. The tensioning means allow individual cables to be tensioned independently. Additional supporting means, such as Cross Braces 14 on Supporting Framework 1, provide physical support to the ribbon cables at regular intervals along their length.

Figure 3, shows detail of how Ribbon Cable 1 is "notched" by creating Perforations 2 between insulated conductors. A length of Solid Insulation 3 is deliberately left between each perforation and the next to provide support for the conductors. The perforations created by notching the cables allow the passage of air through the grid formed by the ribbon cables, as the diaphragm moves in response to the audio signal.

2. Method of Compensating for Reduction in Output Sound Pressure Level of an Electrostatic Loudspeaker, Caused by Front to Back Cancellation Effects.

Background to the Invention

Front to back cancellation can occur with most flat panel loudspeakers, including electrostatic loudspeakers, due to physical movement of air between front and back, over the edges of the panel. This results in a reduction in sound pressure level over a specific frequency range, resulting in sound colouration, such as a perceived lack of bass response. The effect typically occurs in the frequency range between 100 Hz and 300 Hz, and reductions in sound pressure level of up to 9 db may occur in this "trough". Compensation by increasing amplifier output in the frequency range concerned, such as by using a graphic equaliser, is generally not a satisfactory solution to the

problem in the case of electrostatics, because it requires an increase in the output voltage swing of the audio amplifier, beyond the range that most amplifiers are capable of.

Preferred Embodiment

A preferred embodiment of electronic circuitry for compensating for a reduction in output sound pressure level of an electrostatic loudspeaker, caused by front to back cancellation effects, is shown in Figure 4. This circuitry is connected between the audio amplifier and the primary winding of the electrostatic loudspeaker transformer. The circuit comprises a resonant circuit and filter. The resonant frequency of the circuit is set to correspond with the frequency at which the maximum reduction in sound pressure level occurs.

Input from the audio amplifier is connected to Terminals 8. At frequencies well below the resonant frequency, inductors 2 and 3 have low impedance, and provide a path for the audio signal. Similarly, at these low frequencies, Capacitors 4, 6, and 7 have high impedance, and provide no signal path. The audio input signal passes via Terminals 8 through Inductors 2 and 3 to the primary winding of Transformer 1, with very little attenuation. Hence, at these frequencies, the circuit has no effect.

Conversely, at frequencies well above the resonant frequency, Capacitors 6 and 7 have low impedance, and provide a signal path. At these high frequencies, Inductors 2 and 3 have high impedance, and provide no signal path. The audio input signal passes via Terminals 8 through Capacitors 6 and 7 to the primary winding of Transformer 1, with very little attenuation.
Hence, at these frequencies, the circuit has no effect.

At or near the resonant frequency, the circuit behaves quite differently. A tuned circuit is formed by Inductor 3, Capacitor 4,and the inductance of Transformer 1 primary winding. Inductor 2 provides sufficient impedance to decouple the very low output impedance of the audio amplifier from the tuned circuit. Resistor 5 determines the Q of the tuned circuit. At or near the resonant frequency, the current flowing through Transformer 1 primary winding builds up over a few cycles to a value that greatly exceeds the value it would have without the tuned circuit present. Hence the audio output of the speaker is increased for frequencies at or near the resonant frequency, which compensates for the front to back cancellation effect. The values of Inductor 3, Capacitor 4, and Resistor 5 are chosen so that the shape of the tuned circuit response curve closely matches the shape of that part of the speaker response curve that requires compensation. It is possible to select values of Inductor 3, Capacitor 4, and Resistor 5 such that there is no reduction in sound pressure level of the loudspeaker in the frequency band where front to back cancellation is occurring.

Typical component values for this circuit are:

Inductor 2	3 mH	Resistor 5	0.47Ω
Inductor 3	9 mH	Capacitor 6	100μF
Capacitor 4	800μF	Capacitor 7	10μF

3. Method of Limiting Peak Audio Frequency Voltages Applied to the Grids of an Electrostatic Loudspeaker

Background to the Invention

To operate effectively, an electrostatic loudspeaker requires the application of high audio frequency voltages between the grids and the electrically charged diaphragm. These voltages are generated by a step up audio transformer, which may typically have a ratio of 1:100. The audio voltages add to the D.C. polarising voltage which must be applied between the diaphragm and the centre tap of the driver transformer. Peak voltages of several thousand volts can occur between the grids of an electrostatic loudspeaker, and this can result in electrical flashovers occurring, with resultant damage to the diaphragm. The probability of flashover can be reduced by increasing the size of the air gap between the grids, but this decreases the sensitivity of the loudspeaker, ie. the sound pressure level produced per watt of audio input.

Hence some form of overvoltage protection is required to limit the peak voltage to a safe level. Various forms of protection are known in the art, including spark gaps and non-linear resistors or semi-conducting devices.

Spark gaps have the disadvantage that a visible and audible discharge occurs during operation, and an audible drop in output of the speaker accompanied by distortion, may occur. Non-linear devices also introduce distortion by clipping of the peaks of the waveform.

Preferred Embodiment

A preferred embodiment for limiting the peak voltage between the grids is shown in Figure 5. A Metal Oxide Varistor 2 (MOV) or similar non-linear device is connected across the high voltage winding of Transformer 1. Several MOV's may be connected in series to achieve the required voltage rating. The protective MOV operates in conjunction with Resonant Circuit and Filter 3 (as described in Item 2. above), to limit overvoltages without introducing any appreciable distortion.

As discussed in Item 2. above, Resonant Circuit and Filter 3 increases the current flowing in the primary of Transformer 1 at or near the resonant frequency to compensate for front to back cancellation effects. Hence the output voltage of Transformer 1 is likely to be highest at these frequencies, and may be two to three times the voltages that occur at other frequencies. The cut-in voltage of the MOV's is typically chosen to be about half of the estimated maximum voltage that can occur. As the MOV's begin to conduct, small amounts of resistive current flow at the peaks of the voltage waveform. This causes an increase in the resistive component of the impedance reflected to the primary of Transformer 1. As this impedance forms part of the tuned circuit (as described in Item 2 above) the circuit becomes more heavily damped and therefore the current in Transformer 1 primary is reduced. This in turn reduces the output voltage of Transformer 1. The whole voltage waveform is effectively compressed by the damping effect, and is not clipped as would occur if the resonant compensating circuit were not present. Because clipping does not occur, there is no audible distortion when the overvoltage protection circuit operates.

4. Method of Improving the Sound Dispersion of an Electrostatic Loudspeaker

Background to the Invention

Electrostatic loudspeakers are bi-polar sound radiators, which means that sound is radiated equally from the front and rear of the loudspeaker. They also radiate a comparatively narrow "beam" of sound, which tends to reduce the size of the effective listening area. Sound dispersion is improved if the speakers are carefully loçated near the corners of a room, so that the sound radiated from the rear of the speaker is reflected from the rear and side walls back towards the listening position. This technique has the disadvantage of restricting the positions in which an electrostatic loudspeaker can be placed within a room.

Preferred Embodiments

Figure 6 shows two preferred embodiments (Labeled A and B in the Figure) of means for improving the sound dispersion of a hybrid electrostatic loudspeaker. These embodiments utilise the woofer enclosure as sound reflecting surfaces which direct the sound waves from the rear of the electrostatic array in particular directions.

Drawings A and B represent plan views of hybrid electrostatic loudspeakers fitted with woofer enclosures configured as sound dispersing means. In each case an Electrostatic Array 1 is mounted on a Base 2. A cone type Woofer 3 is installed in a triangular Enclosure 4. The enclosure typically about half the height of Electrostatic Array 1. Sound waves radiated from the rear of Electrostatic Array 1 are reflected off the angled face(s) of Enclosure 4 and directed sideways, as shown by the dotted arrows.

Drawing C shows a hybrid electrostatic loudspeaker with a square woofer enclosure, also configured to reflect sideways the sound waves radiated from the rear of the electrostatic array. A triangular woofer enclosure is preferable because it also has other advantages in that it is more rigid than a square or rectangular enclosure, and as there are no parallel faces, internal standing waves are eliminated.

The use of angled reflecting surfaces allows the speaker to be placed in a wider range of positions in a room, including parallel to a rear wall. Placement of a conventional electrostatic loudspeaker parallel to a rear wall is undesirable because sound waves from the rear of the speaker may be reflected back into the array, causing cancellation effects at particular frequencies.

It will be appreciated that many variations in the embodiment of a woofer enclosure configured to provide sound reflecting surfaces are possible, and the arrangements shown in Figure 6 are typical examples only, and are not to be taken as limiting the scope of the invention in any way.

Claims:

1. A method of constructing the grids of an electrostatic loudspeaker using flat ribbon cable, the conductors of which are electrically connected together.

2. The electrostatic loudspeaker grids of Claim 1 where individual conductors or groups of conductors in the ribbon cable are connected together through external circuitry such as delay networks.

3. A method of compensating for a reduction in sound pressure level of an electrostatic loudspeaker caused by front to back cancellation effects, utilising a resonant circuit and filter in the primary circuit of the electrostatic loudspeaker transformer to boost the output of the loudspeaker in the frequency band at which cancellation occurs.

4. A method of limiting the peak voltage between the grids of an electrostatic loudspeaker incorporating the resonant circuit and filter of Claim 3, by utilising a metal oxide varistor or other non-linear device connected between the grids to damp the resonant circuit and thereby compress the voltage waveform when conduction through the metal oxide varistor or other non-linear device occurs.

5. A method of improving the sound dispersion of a hybrid electrostatic loudspeaker by utilising a woofer enclosure incorporating sound reflecting surfaces to re-direct sound waves emanating from the rear surface of the electrostatic array.

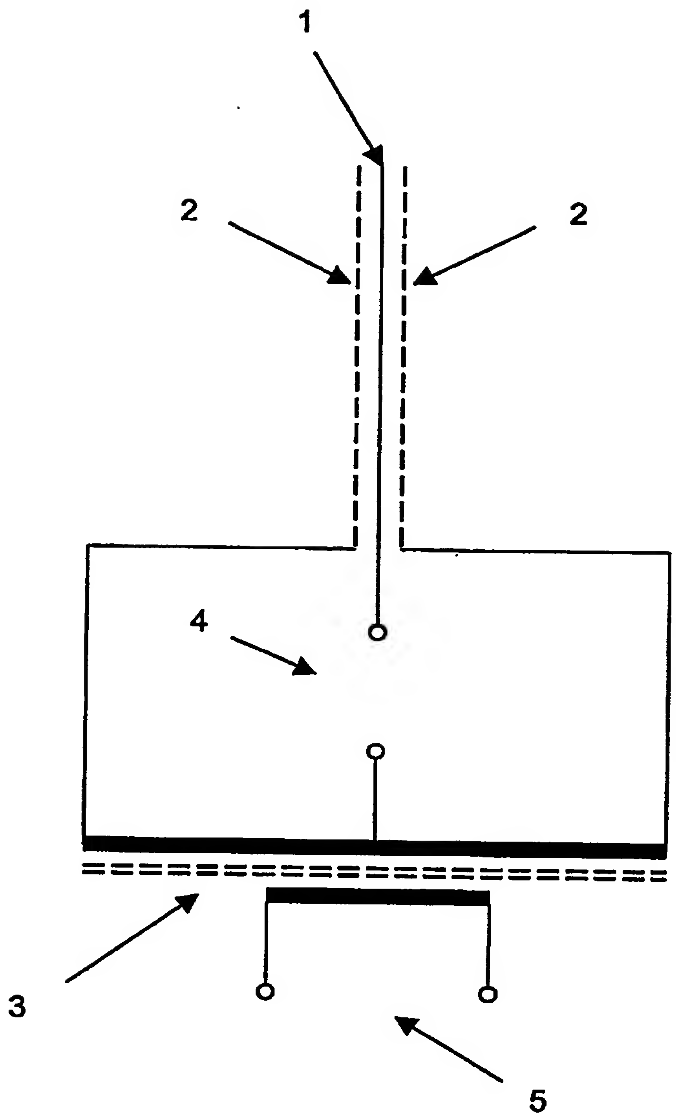

FIG. 1

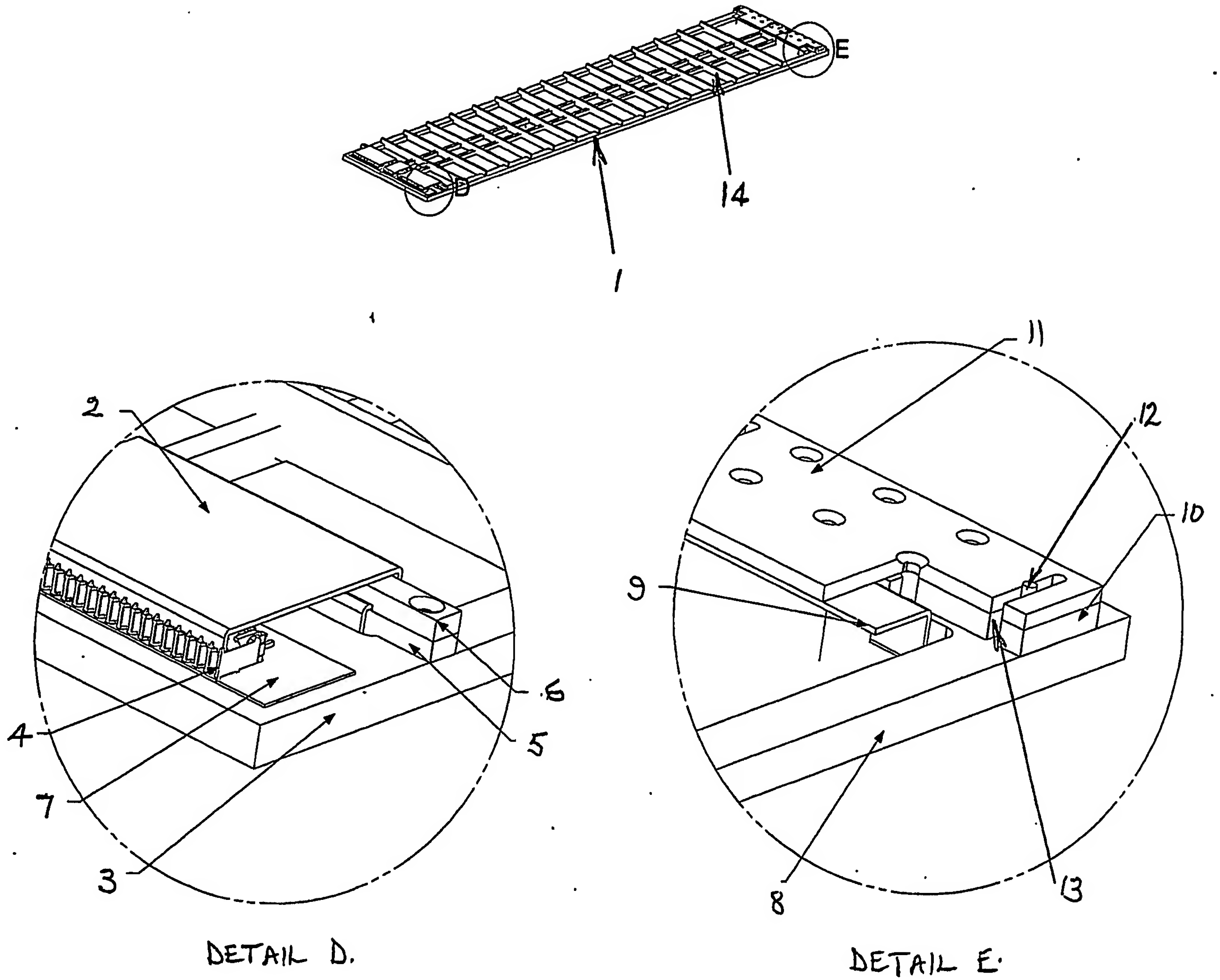

FIG. 2

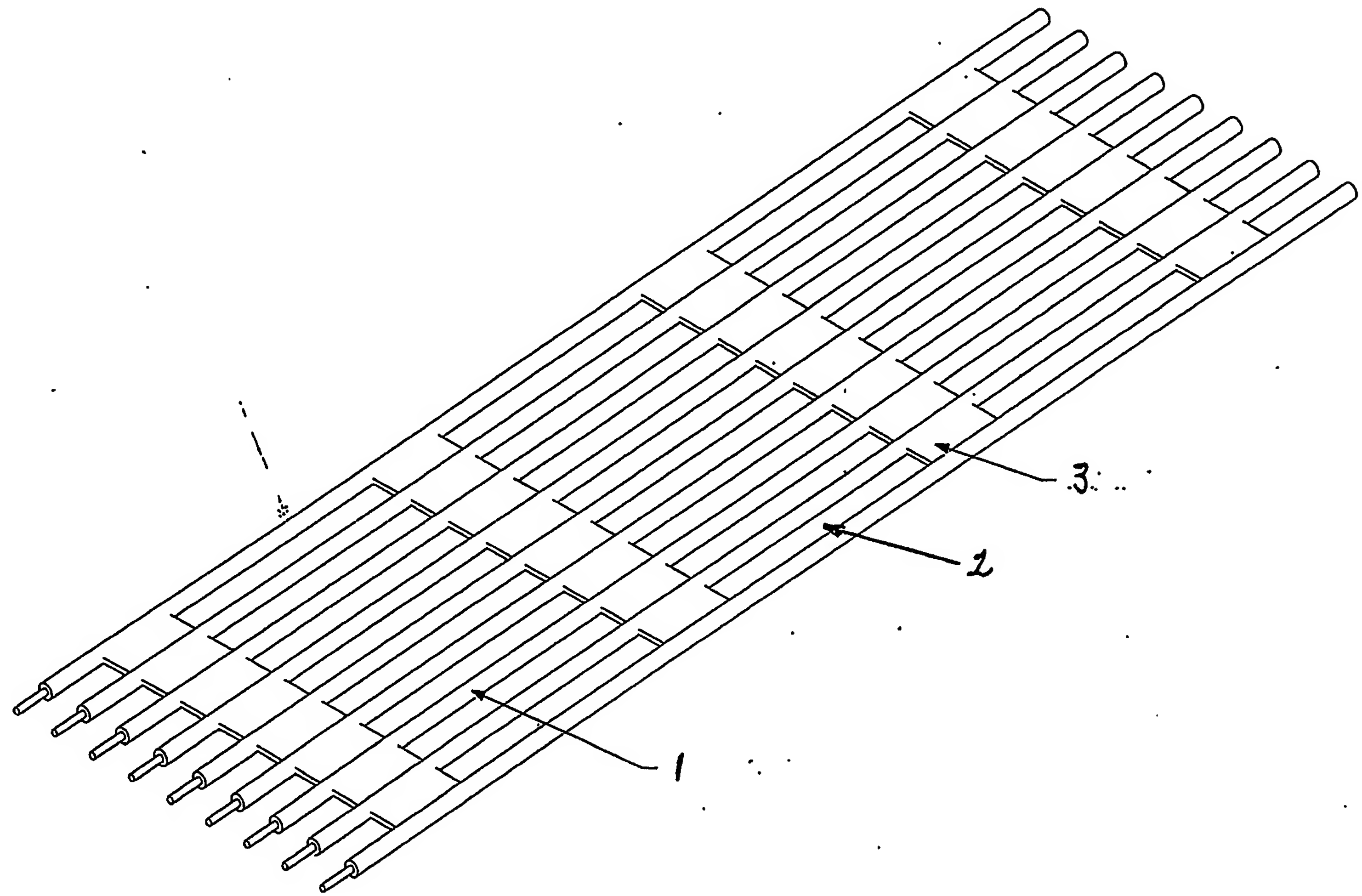

FIG. 3

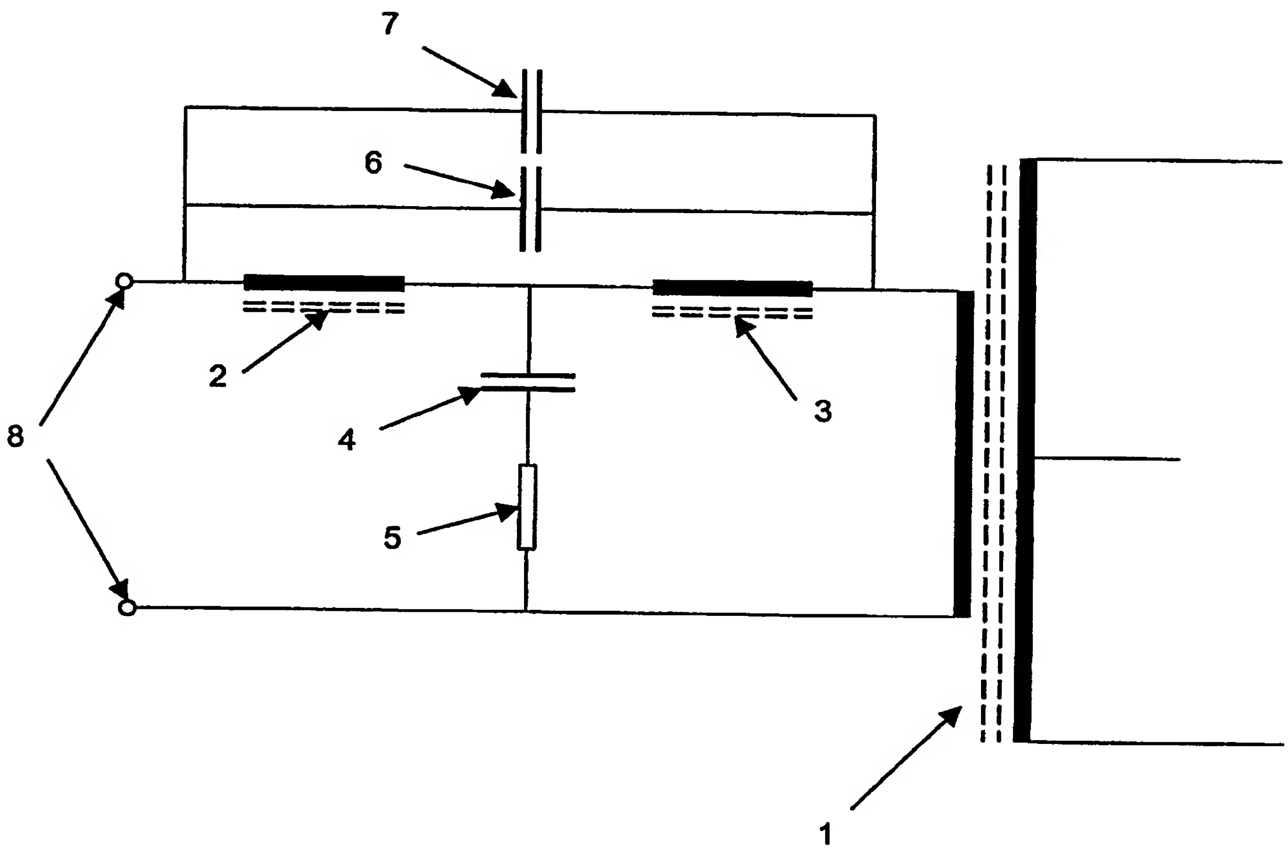

FIG. 4

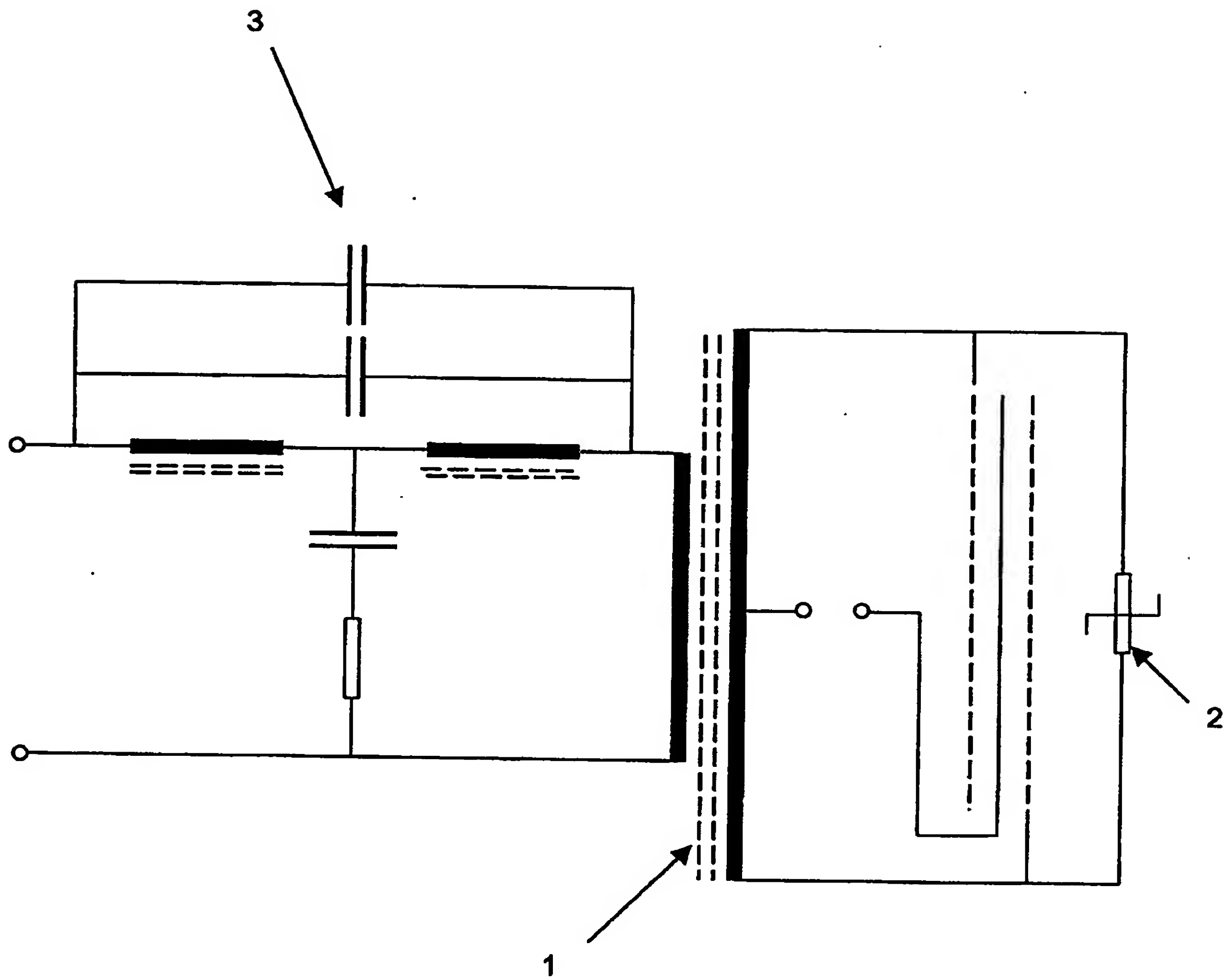

FIG. 5

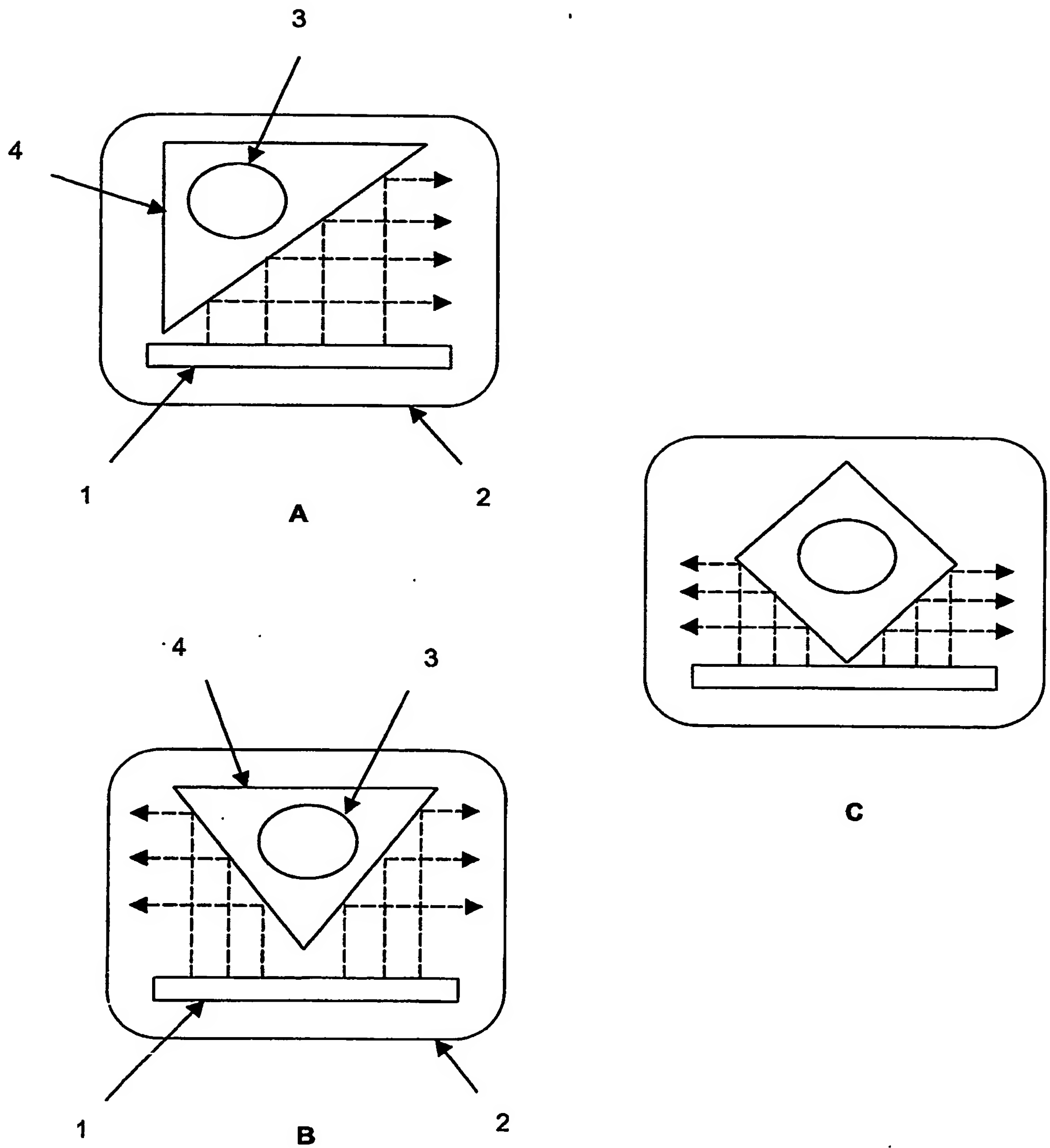

FIG. 6